

Large-Amplitude 2.65-d Oscillation in the VY Scl-Type star V425 Cas

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Abstract

From long-term photometry of a VY Scl-type star, V425 Cas, between 1998 and 2000, we discovered a short-term, large-amplitude (up to 1.5 mag) variations. The variation was well represented by a single period of 2.65 d. The large amplitude and the profile of the folded light curve suggest that the dwarf nova-type disk instability is responsible for this variation. The shortness of the period is unprecedented in hydrogen-rich cataclysmic variables. Given the recent emerging evidence that the irradiation from white dwarfs in VY Scl-type systems affect their light behavior, we propose a possibility that this unique variation in V425 Cas can be explained by the combination of the dwarf nova-type disk instability and irradiation. Similar short-period “outbursts” have been known in X-ray transients (V518 Per), and helium cataclysmic variables (CR Boo and V803 Cen). We discuss the possibility that these phenomena have a common origin to the unique variation in V425 Cas.

Key words: Accretion: accretion disks — Stars: cataclysmic variables — Stars: dwarf novae — Stars: oscillations — Stars: individual (V425 Cas)

1. Introduction

Cataclysmic variables (CVs) are close binary systems consisting of a white dwarf and a red dwarf secondary filling the Roche lobe. The matter transferred from the secondary forms an accretion disk around the white dwarf. Instabilities in the accretion disk result in various kinds of activities seen in CVs. The two most relevant instabilities are thermal and tidal instabilities, which are responsible for dwarf nova-type outbursts and superhumps, respectively (see [te\[cite\].osa96Osaki \(1996\)](#) ([\[cite\]cite.osa96Osaki \(1996\)](#)) for a review). In systems having orbital periods longer than three hours, thermal instability governs the general behavior. Accretion disks become thermally stable at high mass-transfer rates (\dot{M}), while disks become thermally unstable in low \dot{M} . The former corresponds to novalike (NL) variables, which do not show outbursts, while the latter corresponds to dwarf novae, which show semi-periodic outbursts. Close to the thermal stability border, there exist systems called as Z Cam stars, which show both standstills, the state corresponding to a NL variable, and a state exhibiting dwarf nova outbursts. The origin of interchanging states in Z Cam stars can be naturally understood with an assumption of varying \dot{M} from the secondary: the high \dot{M} -state corresponds to standstills, while the low \dot{M} -state the dwarf nova phase. There exist a small group of NL variables which show temporary reduction or cessation of \dot{M} from the secondary, namely VY Scl-type stars ([000 \[cite\]cite.war95Warner \(1995\)](#)). The low states (reduced

\dot{M} -states) of VY Scl stars are hard to interpret in the scheme of the standard disk instability theory. If the disk follows the same evolution as in Z Cam stars in response to the temporary reduction of \dot{M} , the system should undergo dwarf nova outbursts ([000 \[cite\]cite.hon94Honeycutt et al. \(1994\)](#), [000 \[cite\]cite.kin98King and Cannizzo \(1998\)](#)). Observations usually show the contrary: the system undergoes a smooth decline from the high to low states ([000 \[cite\]cite.hon94Honeycutt et al. \(1994\)](#); see also [000 \[cite\]cite.gre98Greiner \(1998\)](#)).

An important clue to understanding the VY Scl-type behavior came from the detection of transient supersoft X-rays from a VY Scl-type system, V751 Cyg ([000 \[cite\]cite.gre99Greiner et al. \(1999\)](#)). From the detection of supersoft X-rays during the low state of V751 Cyg, [te\[cite\].gre99Greiner et al. \(1999\)](#) ([\[cite\]cite.gre99Greiner et al. \(1999\)](#)) suggested that steady nuclear burning is taking place on the white dwarf of V751 Cyg. [te\[cite\].gre99Greiner et al. \(1999\)](#) ([\[cite\]cite.gre99Greiner et al. \(1999\)](#)) further suggested the possibility that VY Scl-type stars comprise a low-mass analog of supersoft X-ray sources (SSXS). This discovery is consistent with the observed high temperature of white dwarfs in VY Scl-type systems (cf. [000 \[cite\]cite.war95Warner \(1995\)](#), table 2.8). [te\[cite\].lea99Leach et al. \(1999\)](#) ([\[cite\]cite.lea99Leach et al. \(1999\)](#)) proposed that, in the presence of the heating from the hot white dwarf, the irradiation on the accretion disk suppresses the thermal instability, which can reproduce the observed light curve of VY Scl-type system in their low-high transitions. This effect, combined with the suggestion by [te\[cite\].gre99Greiner et al.](#)

(1999) ([cite]cite.gre99Greiner et al. (1999)), would be a promising candidate for the explanation of the behavior of VY Scl-type stars. In this paper, we report on the discovery of large-amplitude oscillations with a period of 2.65 d, in a VY Scl-type system V425 Cas (000 [cite]cite.wen87Wenzel (1987)), which we regard as a further evidence for the effect of irradiation.

2. Observation

A fading of V425 Cas was detected by one of authors (T. Kinnunen) in 1997 August. The object soon returned to its high state, and remained at around mag 14.5 until early 1998. The object was again caught in faint state at the beginning of the next observing season (1998 August). We observed the system with a CCD in three seasons, 1998 – early 1999, late 1999 – early 2000 and early 2000. The CCD observations were done using an unfiltered ST-7 camera attached to the Meade 25-cm Schmidt-Cassegrain telescope. The exposure time was 30 s. The images were dark-subtracted, flat-fielded, and analyzed using the JavaTM-based PSF photometry package developed by one of the authors (T. Kato). The magnitudes were determined relative to GSC 3985.1444 (Tycho-2 magnitude: $V = 11.07 \pm 0.17$, $B - V = +0.17 \pm 0.10$), whose constancy was confirmed using GSC 3985.1525. The log of observations are given in the table (N represents the number of frames).

3. Results

Fig. 1 shows the light curve of the 1998–1999 season, when the object stayed 1.0–2.0 mag below the high-state level. Large-amplitude, rapid variations are clearly seen with a time scale of a few days. Such a large-amplitude, short-term variation was never observed in any hydrogen-rich CVs, including VY Scl-type stars.

Fig. 2 shows the result of period analysis, using the Phase Dispersion Minimization (PDM) method (000 [cite]cite.ste78Stellingwerf (1978)). The strongest period is seen at $P = 2.65$ d. No other significant period was found between $P = 2$ d and $P = 5$ d. Since our observations were basically sampled once per night, we can not completely rule out the possibility of a shorter period. We have searched signals around the orbital period of V425 Cas (0.1496 d, 000 [cite]cite.sha83Shafter (1983)) and found no significant period representing the overall light variation. This strongly indicates that the variation is not related to its orbital motion. The low inclination angle (25° , 000 [cite]cite.sha83Shafter (1983)) also makes unlikely orbital modulations as a major cause of variation.

Fig. 3 shows the light curve in the 1998–1999 season folded by this 2.65 d period. The averaged light curve clearly shows 0.6–0.7 mag modulations, having a rapid rise and a slower decline. The profile of the light curve resembles those of dwarf nova outbursts with short recurrence times.

Fig. 4 shows the light curve in the 1999–2000 season, in which the object was at a similar brightness level as in the

Table 1. Log of observations (1)

Month	UT (start–end)	N	mag	error
1998				
December	12.454 – 12.505	131	4.625	0.148
	13.369 – 13.494	304	5.224	0.241
	15.366 – 15.491	252	5.048	0.831
	16.368 – 16.493	303	5.129	0.167
	17.393 – 17.469	69	5.517	1.860
	18.398 – 18.487	208	4.945	0.155
	19.366 – 19.495	308	4.559	0.200
	20.381 – 20.465	185	4.366	0.208
	21.365 – 21.446	202	4.309	0.130
	22.360 – 22.409	36	5.298	1.241
	23.354 – 23.436	199	4.437	0.166
	25.359 – 25.468	267	5.196	0.185
	26.365 – 26.501	175	5.201	1.084
	27.364 – 27.422	139	4.756	0.112
	28.414 – 28.444	78	4.438	0.129
	29.358 – 29.397	100	5.452	0.397
	30.358 – 30.420	160	4.498	0.248
	31.374 – 31.381	5	3.865	0.593
1999				
January	1.354 – 1.362	19	5.307	0.317
	2.367 – 2.371	9	4.230	0.246
	3.355 – 3.366	28	4.988	0.606
	4.383 – 4.391	20	5.198	0.265
	5.358 – 5.370	31	4.869	0.175
	7.360 – 7.365	14	4.927	0.606
	8.359 – 8.367	19	4.353	0.175
	9.365 – 9.375	26	5.197	1.102
	10.362 – 10.368	14	4.610	0.204
	11.365 – 11.369	10	4.350	0.125
	12.363 – 12.371	20	5.669	0.594
	13.363 – 13.368	11	4.553	0.318
	14.433	1	3.819	–
	15.364 – 15.371	19	5.401	0.643

1998–1999 season (the averaged magnitudes of these two seasons agree within 0.05 mag). Nevertheless, the 2.65-d period had completely disappeared. Period analysis of the data did not yield any significant periodicity.

Fig. 5 shows the light curve in the late 2000 season. The object had further faded by ~ 1.0 mag at the beginning of this season. There is an evidence of a further fade in 2000 November – December. It is likely the object was entering a deep low state during this season.

4. Discussion

The large amplitude (up to 1.5 mag, and 0.6–0.7 mag in average, which is close to a factor of two flux variation) of the variations far exceeds those of known (local) disk oscillations, such as quasi-periodic oscillations, in CVs. The amplitude more suggests that dwarf nova-type disk instability is taking place, which is also consistent with the observed profile of variation. The main difference from the ordinary dwarf novae is the extreme shortness of the recur-

Table 2. Log of observations (2)

Month	UT (start–end)	N	mag	error
1999				
January	16.377 – 16.384	8	4.123	0.527
	17.388 – 17.393	14	5.344	0.217
	18.366 – 18.372	16	5.104	0.359
	20.421 – 20.426	14	4.294	0.110
	21.367 – 21.371	10	4.060	0.613
	22.390 – 22.394	12	5.051	0.178
	23.368 – 23.375	20	5.069	0.651
	25.418 – 25.424	15	4.565	0.986
	26.371 – 26.382	28	4.380	0.164
	27.536 – 27.540	12	4.663	0.315
	28.377 – 28.380	11	5.187	0.347
	29.374 – 29.379	13	4.299	0.150
	30.373 – 30.379	16	5.101	0.379
	31.375 – 31.379	9	4.918	0.236
February	1.427 – 1.445	49	4.771	0.401
	2.375 – 2.384	23	4.825	0.442
	4.564 – 4.574	23	4.848	1.164
	5.434 – 5.439	4	>4.5	–
	6.378 – 6.386	21	5.109	0.326
	7.386 – 7.401	39	4.456	0.148
	8.379 – 8.398	49	5.320	0.422
	9.383 – 9.396	33	4.530	0.512
	10.385 – 10.396	15	4.756	1.207
	13.410 – 13.427	19	4.807	0.749
	14.385 – 14.395	26	5.282	0.373
	15.386 – 15.410	38	4.470	0.931
	16.386 – 16.392	18	5.411	0.926
	17.393 – 17.397	10	4.241	0.241
	19.404 – 19.406	5	4.159	0.086
	20.390 – 20.396	15	5.174	0.507
	21.399 – 21.401	7	4.869	0.511
	22.390 – 22.394	9	4.400	0.381
	23.425 – 23.427	6	4.860	0.286

Table 3. Log of observations (3)

Month	UT (start–end)	N	mag	error
1999				
February	25.394 – 25.396	6	4.257	0.284
	27.408 – 27.412	4	3.850	0.495
	28.393 – 28.399	16	4.277	0.214
March	1.397 – 1.403	15	5.013	0.369
	3.396 – 3.401	11	5.246	0.689
	5.402 – 5.408	10	5.147	1.049
	6.397 – 6.401	12	4.878	0.876
	10.399 – 10.407	21	4.915	0.859
October	11.400 – 11.407	14	5.027	1.206
	16.404 – 16.411	19	6.527	2.544
	1.669 – 1.672	10	4.920	0.141
	3.668	1	5.352	–
	5.636 – 5.639	8	5.185	0.167
	9.710 – 9.712	2	4.952	0.210
	10.646 – 10.674	67	4.773	0.322
	11.647 – 11.649	5	4.840	0.109
	17.636 – 17.640	10	4.874	0.201
	18.651 – 18.651	2	4.565	0.501
November	20.603 – 20.606	8	4.786	0.106
	22.613 – 22.616	10	4.705	0.198
	23.611 – 23.615	10	4.758	0.148
	24.610 – 24.613	10	4.820	0.097
	25.601 – 25.605	10	4.779	0.127
	28.646 – 28.650	10	4.940	0.590
	29.588 – 29.594	17	4.754	0.303
	30.577 – 30.581	11	4.604	0.327
	3.562 – 3.563	5	4.654	0.070
	4.562 – 4.564	5	4.661	0.086
	5.554 – 5.557	8	4.671	0.140
	19.565 – 19.567	5	4.588	0.062
	21.562 – 21.564	5	4.791	0.140
	22.564 – 22.565	5	4.669	0.271
	25.753 – 25.757	11	4.659	0.612

rent time. Dwarf novae with orbital periods around that of V425 Cas have typical recurrence time of ten to a hundred of days, the shortest known one being AM Cas having a recurrent time as short as 8 d (cf. 000 [cite]cite.rit98Ritter and Kolb (1998)). The recurrence time of dwarf novae is basically governed by the two factors, namely the viscous drift time in low \dot{M} systems and the build-up time in the outer disk torus in high \dot{M} systems (cf. 000 [cite]cite.osa96Osaki (1996)). The shortest limit of recurrence time is regulated by the latter factor, which makes the recurrence time approximately inversely proportional to \dot{M} . Above the critical \dot{M} , the disk becomes thermally stable, and this determines the shortest limit. According to calculations by te[cite]cite.ich94Ichikawa and Osaki (1994) ([cite]cite.ich94Ichikawa and Osaki (1994)), the expected minimum period is slightly below ~ 10 d, which is in good agreement with the AM Cas case. A different mechanism is therefore needed to explain the extremely short recurrent time in V425 Cas.

A clue to this problem can be found in another exam-

ple of a striking departure of recurrence time from the disk-instability theory: “purr” type outbursts observed during the outburst of an X-ray transient, V518 Per = GRO J0422+32 (000 [cite]cite.min94Mineshige (1994)), which had a recurrence time of ~ 10 d, which is several times to an order of magnitude shorter than the expected recurrence time from the disk instability model. te[cite]cite.min94Mineshige (1994) ([cite]cite.min94Mineshige (1994)) argued that X-ray irradiation on the accretion disk can effectively increase the disk temperature, and suppress the instability in inner portions of the disk, producing small-scale purr-type outbursts (for model calculations, see 000 [cite]cite.min90Mineshige and Shields (1990)). This scheme could apply to accretion disks in CVs, if there is an appropriate source of irradiation. te[cite]cite.min94Mineshige (1994) ([cite]cite.min94Mineshige (1994)) required an X-ray luminosity of $L_X = 10^{35}$ erg s $^{-1}$ in producing purr-type outbursts. Since the observed X-ray luminosity during a low state of the VY Scl-type star V751 Cyg was estimated to be $L_X = 10^{34-36}$ erg s $^{-1}$ (000

Table 4. Log of observations (4)

Month	UT (start–end)	N	mag	error
1999				
November	26.754 – 26.757	10	4.877	0.266
	28.688 – 28.692	11	4.913	0.171
	29.543 – 29.544	5	4.649	0.148
	30.543 – 30.544	3	4.783	0.137
December	3.656 – 3.659	10	4.649	0.131
	7.652 – 7.656	10	4.698	0.183
	8.637 – 8.640	10	4.879	0.204
	9.478 – 9.479	5	4.699	0.182
	10.473 – 10.474	5	4.469	0.151
	11.463 – 11.464	5	4.877	0.486
	14.405 – 14.406	5	4.843	0.099
	15.407 – 15.409	5	4.720	0.100
	16.413 – 16.414	5	4.843	0.068
	19.424 – 19.426	5	4.585	0.253
	20.419 – 20.420	5	4.485	0.199
	21.419 – 21.420	5	4.797	0.122
	22.422 – 22.423	5	4.632	0.170
	23.412 – 23.413	5	4.902	0.104
	24.412 – 24.413	4	4.736	0.196
	25.413 – 25.415	5	4.468	0.097
	26.412	1	4.356	–
	27.405 – 27.406	5	4.721	0.094
	28.407 – 28.408	5	4.615	0.139
	29.495 – 29.497	5	4.909	0.403
	30.488 – 30.489	5	4.678	0.102
	31.487 – 31.488	5	4.580	0.098
2000				
January	3.475 – 3.477	5	4.625	0.123
	8.458 – 8.459	5	4.730	0.309
	10.449 – 10.474	3	4.822	1.084
	11.456 – 11.458	5	4.757	0.140
	14.379 – 14.381	5	4.491	0.278
	15.363 – 15.371	22	4.716	0.768

Table 5. Log of observations (5)

Month	UT (start–end)	N	mag	error
2000				
January	17.370 – 17.374	5	3.386	0.475
	18.370 – 18.373	9	4.432	0.167
	20.367 – 20.371	9	4.164	0.393
	21.378 – 21.382	10	4.744	0.263
	22.390 – 22.391	3	3.988	0.477
	24.375 – 24.378	7	3.876	0.613
	25.377 – 25.382	14	4.641	0.265
	26.376 – 26.378	6	4.632	0.169
	27.377 – 27.379	5	4.565	0.205
	28.393 – 28.395	7	4.846	0.441
	29.381 – 29.384	7	4.675	0.192
	30.383 – 30.386	7	4.657	0.897
	31.380 – 31.382	7	4.934	0.505
February	1.395 – 1.397	6	4.984	0.427
	2.390 – 2.392	5	4.453	0.156
	4.393 – 4.393	2	4.905	0.088
	5.387 – 5.388	5	4.703	0.090
	7.385 – 7.386	5	4.647	0.263
	8.388 – 8.390	2	5.152	0.256
	9.396 – 9.398	5	4.826	0.216
	10.391 – 10.392	5	4.991	0.678
	11.394 – 11.395	3	3.995	0.396
	12.390 – 12.392	5	4.756	0.465
September	13.386 – 13.387	5	4.090	0.665
	18.732 – 18.737	12	5.741	1.296
	19.757 – 19.762	12	5.642	0.134
	20.752 – 20.764	32	5.861	0.357
	24.636 – 24.639	10	5.667	0.168
	26.785 – 26.789	10	5.923	0.208
	27.603 – 27.606	10	5.939	0.177
	28.619 – 28.623	10	5.694	0.252
	29.584 – 29.587	9	5.084	0.132
October	1.584 – 1.589	12	5.531	0.156
	9.638 – 9.641	10	5.528	0.305
	10.671 – 10.676	12	5.682	0.328
	11.617 – 11.620	10	5.682	0.494
	12.668 – 12.671	3	4.665	0.854
	22.552 – 22.556	13	6.016	0.356
November	2.545 – 2.547	7	6.253	0.253
December				

[cite]cite.gre99Greiner et al. (1999)), the effect of irradiation in VY Scl-type systems is expected to be enough to produce similar purr-type outbursts in CVs (CVs generally have smaller accretion disks than in X-ray transients, which would make even a lower L_X to work equally efficiently). We thus regard the present discovery of dwarf nova-like oscillations in V425 Cas as another promising evidence for the effect of irradiation in VY Scl-type systems. The disappearance of this kind of oscillations in the 1999–2000 season may be explained, in the same context, by the reduction of irradiation, due to the exhaustion of the accreted matter after a long-lasting of low-accretion state. The termination of accretion or the exhaustion of the accreted matter probably led to a further fade observed within the following eight months.

Yet another intriguing similarity is found in dwarf nova-like oscillations in helium CVs (AM CVn stars). Two examples are known: CR Boo ($P \sim 19$ hr, 000 [cite]cite.pat97Pettersen et al. (1997)) and V803 Cen ($P = 20\text{--}23$ hr,

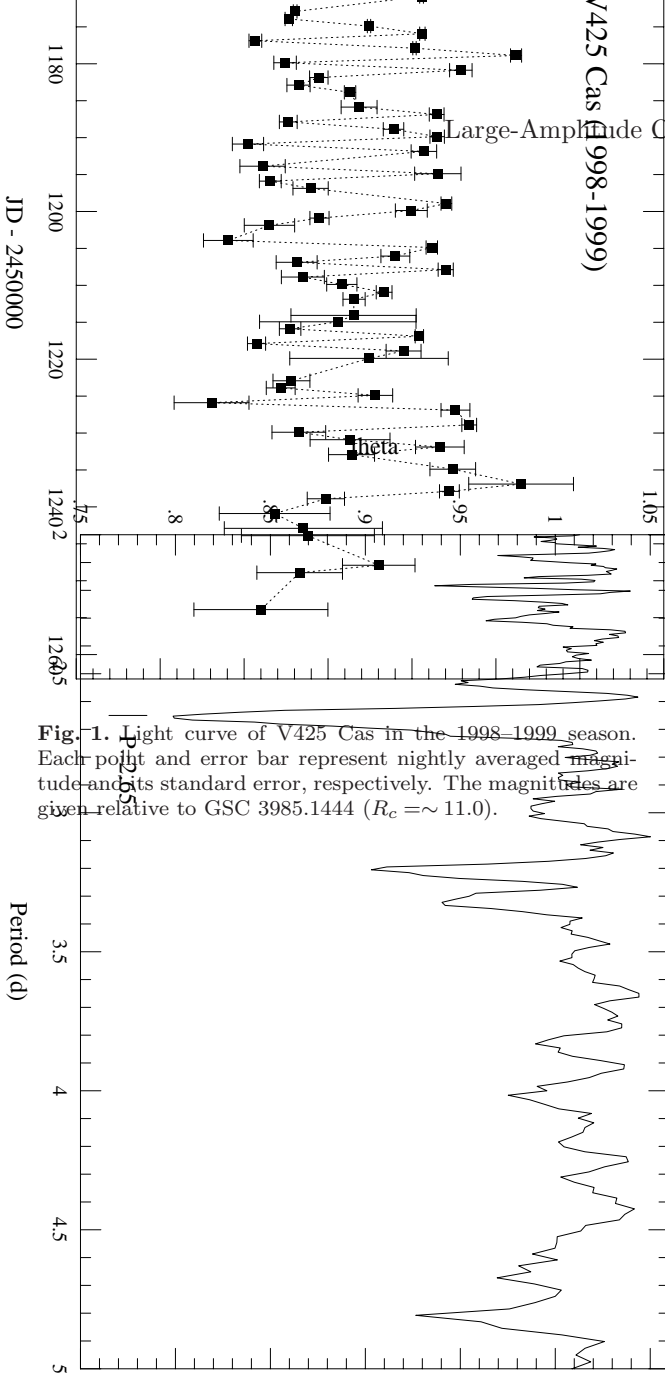


Fig. 1. Light curve of V425 Cas in the 1998–1999 season. Each point and error bar represent nightly averaged magnitude and its standard error, respectively. The magnitudes are given relative to GSC 3985.1444 ($R_c \approx 11.0$).

Fig. 2. Period analysis of V425 Cas in the 1998–1999 season.

000 [cite]cite.pat00Petterson et al. (2000), 000 [cite]cite.kat01Kato et al. (2001)). te[cite]cite.pat97Petterson et al. (1997) ([cite]cite.pat97Petterson et al. (1997)) proposed that this oscillation in CR Boo can be understood as an extension of outbursts in hydrogen-rich dwarf novae, using the known relations (Kukarkin-Parenago’s relation and Bailey’s relation) in hydrogen-rich dwarf novae. However, the assessment of the period should require calculations in helium accretion disks. te[cite]cite.tsu97Tsugawa and Osaki (1997) ([cite]cite.tsu97Tsugawa and Osaki (1997)) applied the dwarf nova-type thermal and tidal instability model to the helium disk systems, and obtained a recurrence time of $\sim 4\text{--}8$ d, which is too long to explain the observed oscillations in CR Boo and V803 Cen. This recurrence time was more appropriately demonstrated in “normal outbursts” of CR

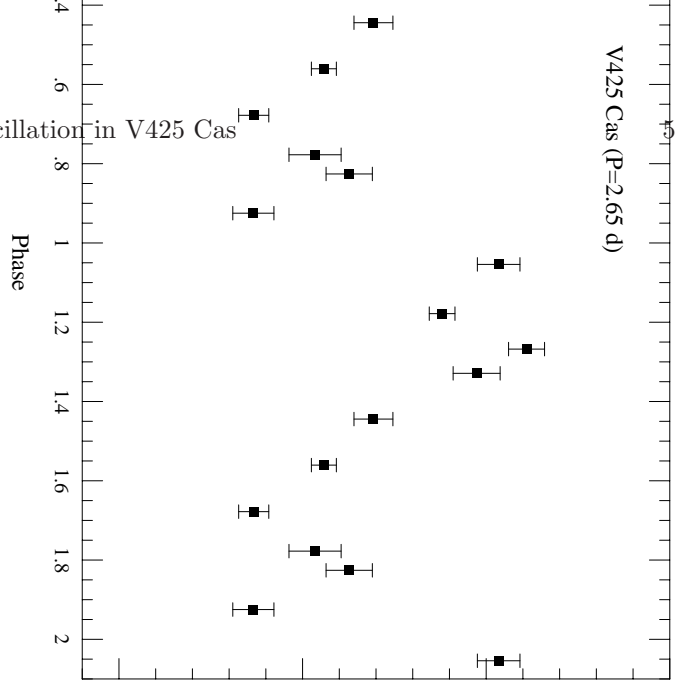


Fig. 3. Averaged light curve of V425 Cas folded by the period of 2.65 d in the 1998–1999 season. The phase is taken arbitrarily.

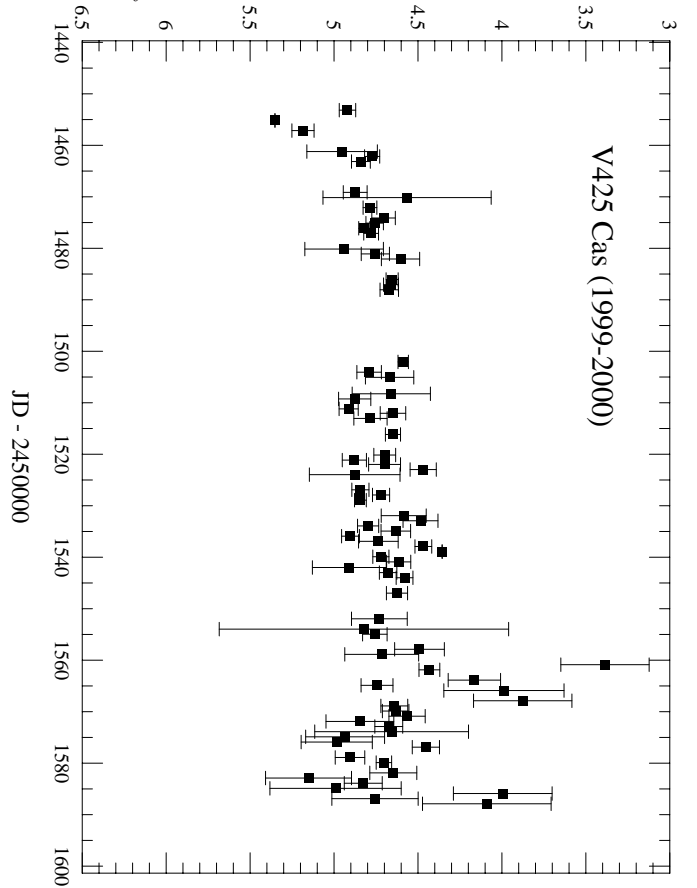


Fig. 4. Light curve of V425 Cas in the 1999–2000 season. The vertical scale and the symbols are the same as in Fig. 1. The 2.65-d oscillations completely disappeared.

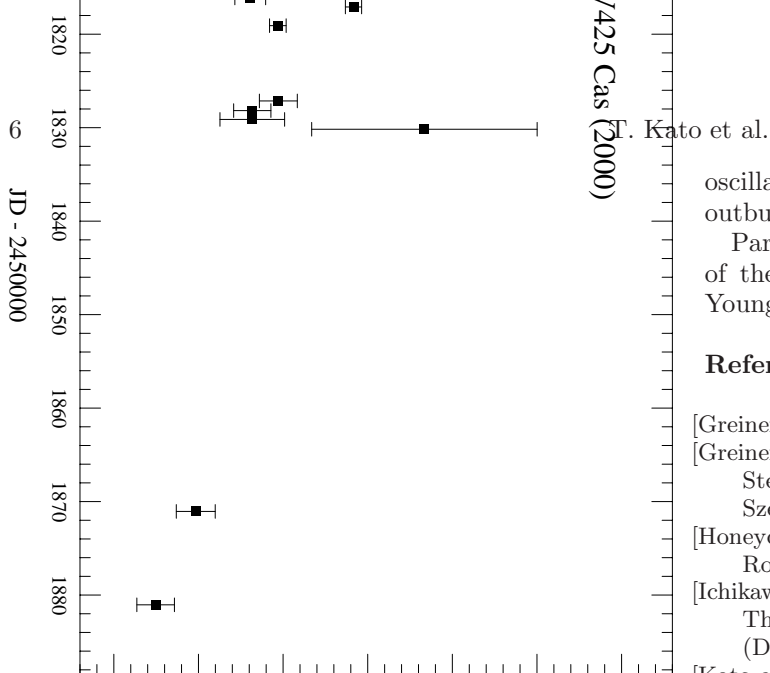


Fig. 5. Light curve of V425 Cas in the late 2000 season. The object had faded considerably compared to the preceding two seasons.

Boo (000 [cite]cite.kat00Kato et al. (2000)) between its superoutbursts recurring with a period of 46 d. [cite]cite.kat00Kato et al. (2000) ([cite]cite.kat00Kato et al. (2000)) suggested that lower-amplitude, short-period oscillations observed by [cite]cite.pat97Petterson et al. (1997) ([cite]cite.pat97Petterson et al. (1997)) may result from the reflection of the cooling and heating waves in the outer region of the accretion disk, and not the full-disk outburst. The mechanism responsible for this effect was not clear at the time of the suggestion by [cite]cite.kat00Kato et al. (2000) ([cite]cite.kat00Kato et al. (2000)), but the relatively strong X-ray flux in both stars inferred from ROSAT observations, the effect of X-ray irradiation would be a promising explanation. Emerging evidences on the observable effect of irradiation in CVs on their outburst behavior, as demonstrated in the present observation, may be also a key to understanding the mystery of outbursts in helium CVs.

5. Conclusion

Our long-term CCD photometry of V425 Cas, during its faint state in 1998–2000, revealed the presence of totally unexpected, unprecedented large-amplitude (0.5–1.5 mag) oscillations with a time scale of a few days. The period analysis of oscillations has demonstrated that this oscillation is well represented by a single period of 2.65 d. The amplitude and mean profile of variation strongly suggests that variation is caused by dwarf nova-type disk instability. The shortness of the period is more difficult to explain. By taking recent discoveries of supersoft X-rays in a low state VY Scl-type star into account, we proposed that the suppression of the thermal instability of the inner accretion disk by irradiation can be responsible for this large-amplitude variation in V425 Cas. This effect of irradiation may also apply to helium cataclysmic variables, which show similar short-period, large-amplitude

oscillations, which were proposed to be dwarf nova-type outbursts.

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